

COPPER-BEARING ROCKS OF VIRGININA COPPER DISTRICT, VIRGINIA AND NORTH CAROLINA¹

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Introduction.

Some time was spent during the month of August, 1901, in a field examination of the Virgilina copper district, and the specimens of the rocks and ores collected were subsequently studied in the laboratory. Study was principally confined, both in the field and laboratory, to the rocks of the area, to determine their nature and origin. The ores were given only secondary consideration.

¹ The author is under special obligations to Professor J. Morgan Clements, of the University of Wisconsin, for kindly reading and criticising this paper in manuscript, and he is indebted to Mr. W. H. Pannebaker, of Virgilina, for the photographs illustrating it.

Brev

The rocks have been designated slates by the earlier workers, which, according to present usage, would imply a metamorphosed sediment. In many instances the characteristic field appearance of the rocks is that of slate or schist, but in their altered phases they are shown, by structural, chemical, and petrographic evidence, to be igneous in origin. Their subsequent alteration developed a schistose structure and an abundance of chlorite, epidote, and a limited quantity of hornblende. These impart to the rock its uniform green color and give the popular name "greenstone."

Recent workers are agreed as to the igneous origin of these rocks, and in a recent paper discussing the type of metalliferous deposits of the area Weed¹ has correctly named the rocks.

Scattered areas of ancient volcanic acid and basic rocks are described by Williams² and Nitze³ immediately to the southwest of the Virgilina district. The rock areas are found in Orange, Chatham, Montgomery, Randolph, and Stanly counties, North Carolina. Nitze describes the basic rocks as being dark green in color, partly massive and partly schistose in structure, and perhaps pyroxenic and at times propylitic in mineral composition. I have not visited these areas, but the descriptions of the basic rocks denote similarity to the Virgilina greenstones.

This paper discusses the evidence for regarding the Virgilina area as one of greatly altered pre-Cambrian volcanic rocks, closely allied to similar areas of ancient volcanics distributed along the Atlantic coast from eastern Canada to Georgia, and certain altered basic rocks in the Lake Superior region. The time which the writer was able to give to this investigation was insufficient to map and define the exact limits of the area.

Previous Work.

The rocks of this immediate area have hitherto received but little attention. No detailed work with respect to the dif-

¹ Trans. Amer. Inst. Min. Engrs., Vol. XXX, p. 453 et seq.

² Journal of Geology, 1894, Vol. II, pp. 1-31.

³ Bulletin No. 3, N. C. Geol. Survey, 1896, pp. 37-43; Bulletin No. 10, *ibid*, 1897, pp. 15, 16

ferentiation and classification of the rocks of the Virgilina district has yet been undertaken. Brief references of a general character dating as far back as the Emmons Survey (1856) are found in numerous reports on economic subjects issued by the North Carolina Geological Survey. Such references as bear directly on the area in question are here reviewed:

After describing the Gillis copper mine in Person county, North Carolina, the earliest discovered one in the belt, Doctor Emmons¹ refers to the rock as follows: "The rock immediately investing the mine is the altered slate belonging to the Taconic system." Emmons first thought the rock was talcose, but later regarded it as argillaceous.

Professor Kerr² makes no special mention of this individual area in his report on the geology of North Carolina, but in defining the "Huronian" rocks of the state he groups the area as the northernmost limit of a belt of Huronian rocks traversing the state in a northeast-southwest direction. Speaking in a general way of the rocks composing the Huronian belt, Kerr mentions the following types: "Quartzite, clay slates, gray, light-colored and drab and greenish." "At some points the quartzites are argillaceous, and at others a few miles west of Smithfield it approaches a fine conglomerate. The clay slates are occasionally slightly hydro-micaceous." He mentions dikes of diabase and dolerite as being common over parts of Granville county. Professor Kerr refers the rocks of certain parts of Granville and Person counties to the lower Laurentian. He mentions the "characteristic and prevalent rocks as being syenite, dolerite, greenstone, amphibolite, granite, porphyry and trachite."

In a geological map of North Carolina, accompanying a report by Kerr and Hanna in 1887, the Person-Granville county area is grouped as the northernmost part of the Huronian.³ A section given at the bottom of the map, extending from the

¹ Geology of the Midland Counties of North Carolina, 1856, p. 344.

² Geology of North Carolina, 1875; Vol. I, pp. 123, 124, and 131.

³ Map accompanying "Ores of North Carolina," 1898.

Tennessee line to Newberne, North Carolina, designates the rocks of the copper belt area as "Huronian slates."

Mr. Hanna¹ describes the copper belt in Person and Granville counties in detail from the standpoint of economic mineralogy. He designates the rocks as schists and slates, and regards them as decidedly chloritic rather than argillaceous, as described by Emmons. Hanna gives the following quotation from a report by Dr. Jackson.

"The strata are occasionally disrupted by dikes; about half a mile from the Gillis, and dipping eastward to it, is a dike bearing N. 20 E., containing abundant sprigs and grains of disseminated native copper. Epidote occurs both in the trap rock and in the quartz, and in the slate strata near the dike, which seems to indicate that the trap-pean rock is of the same geological age as the quartz veins."

Mr. Lewis² describes areas of medium fine and compact grain biotite granites, occurring immediately to the east of the copper belt proper, in Granville and adjoining eastern counties.

In his description of the iron ore deposits in the northwestern part of Granville county, Mr. Nitze³ makes the following reference to the rocks: "Geologically they [iron ores] occur in the crystalline slates and schists, . . . lying conformably between slate walls. . . ." He further mentions small crystals of magnetite occurring in gray micaceous schist coated with malachite.

Nitze and Hanna⁴ mention in "Gold Deposits of North Carolina" the principal copper mines in the copper belt, giving assays of the ores and describing in some detail the topography and general geologic features. They designate the rock as schist.

Pages 37 to 43 of the same report describe the occurrence of ancient acid volcanics found in the same belt, but directly south-

¹ Ores of North Carolina, 1888, p. 215.

² Notes on Building and Ornamental Stones, First Biennial Report, N. C. Geol. Survey, 1893, p. 75.

³ Iron Ores of North Carolina, N. C. Geol. Survey, Bulletin No. 1, 1893, p. 47; Engineering and Mining Journal, 1892, Vol. 53, p. 447.

⁴ Gold Deposits of North Carolina, N. C. Geol. Survey, Bulletin No. 3, 1896, p. 52.

west of the Virgilina area. The scattered areas lie principally in Chatham and Orange counties, within short distances of Raleigh and Chapel Hill. The close resemblance of certain ones in structure and composition to the rhyolites of South Mountain in Pennsylvania is noted. The localities were visited by Professor George H. Williams, in company with Professor J. A. Holmes, in the summer of 1893, and afterward discussed in the *Journal of Geology* for 1894 by Williams.¹ They are referred to as pre-Cambrian in age, and are suggested as probably being contemporaneous with the somewhat analogous rocks of the South mountain, in Maryland and Pennsylvania.

In describing the Carolina Gold Belt area, situated in the central Piedmont region and crossing the central part of the state in a southwesterly direction, Nitze and Wilkens² again refer to the kinds and distribution of the ancient volcanic rocks. Their description follows:³

"The volcanic rocks occupy irregular patches along the eastern border of the belt, in close proximity to the western edges of the Jura-Trias basins. They comprise both acid and basic types. The acid rocks are generally devitrified to such an extent that their real character is no longer recognizable to the naked eye, and they appear as ordinary cherts or hornstones, although flow structure is at times still discernible. Microscopic examination shows them to belong to the class of rhyolites and quartz porphyries. They are sometimes sheared into schists, as for instance at the Haile mine, South Carolina. The basic types are dark green in color and perhaps pyroxenic in composition; they are sometimes massive porphyrites, but more generally sheared into schists. The pyroclastic breccias consist of angular fragments of the acid rhyolites and porphyries in a basic matrix. The age of these ancient volcanics is believed to be pre-Cambrian. They seem to be analogous to, and probably contemporaneous with, similar rocks of the South mountain in Maryland and Pennsylvania, and other points along the Atlantic coast."

Professor George H. Williams⁴ published in 1894 a very important paper on the distribution of the ancient volcanic rocks along the Atlantic Coast region. Attention is directed

¹ *Journal of Geology*, 1894, Vol. II, pp. 1-31.

² *Gold Mining in North Carolina, et cetera*, N. C. Geol. Survey, Bulletin No. 10, 1897, pp. 15, 16.

³ *Ibid.*, p. 16.

⁴ *Journal of Geology*, 1894, Vol. II, pp. 1-31.

in the paper to the area immediately southwest of the Virgilina district, in which occur both acid and basic eruptives, mostly acid, of pre-Cambrian age.

Mr. W. H. Weed¹ recently published a valuable paper treating in some detail the type of ore deposits in this belt and the important economic features. He refers to the rocks of the district as follows:

"The country-rock is schist, in a few places massive enough to be called gneiss. . . . The rocks are all of igneous origin—even the softest and most shaly show this character in thin sections under the microscope. But in a few instances only is the igneous nature of the schists recognizable to the eye. This was observed at the Thomas mine, where a purplish rock is clearly a porphyritic meta-andesite. These schists are cut by dikes of later igneous rock (diabase). The only one seen by the writer was that exposed in the Blue Wing mine.

. . . . Apart from the dykes, however, I would say, on the strength of field-observations alone, that the rocks are of igneous origin, and belong to the various porphyries which have been discovered in the Appalachian belt. This conclusion is confirmed by the microscopic examination of thin sections, which has shown the rocks to be altered andesites, that is meta-andesites and andesite tuffs."

General Field Characters and Occurrence.

As seen from the accompanying map, the area is located near the eastern border of the Piedmont plain, in Halifax county, Virginia, and Person and Granville counties, in North Carolina, 47 miles east of Danville. The belt occupies a low, flat-topped, though somewhat conspicuous, ridge, which trends a few degrees west of south and slopes very gradually to the east and west. It will average 100 to 200 feet in elevation above the neighboring stream valleys. The cross-drainages are all small, but the ridge is flanked by several large ones on the west and northwest sides. The ridge is traced northward to the Dan River valley, in Virginia, some 10 miles north of the state line. In North Carolina its southward extension is estimated by Hanna² to be about 30 miles, reaching nearly to Durham. Prospecting is confined, however, to an approxi-

¹ Types of Copper Deposits in the Southern United States, *Trans. Amer. Inst. Min. Engrs.*, 1901, Vol. XXX, pp. 453, 454.

² *Ores of North Carolina*, Raleigh, 1888, p. 215.

mate north-south distance of 18 miles along the ridge and to an average cross-distance of from 2 to 3 miles. Although of no conspicuous height, the ridge forms a somewhat prominent feature in the landscape.

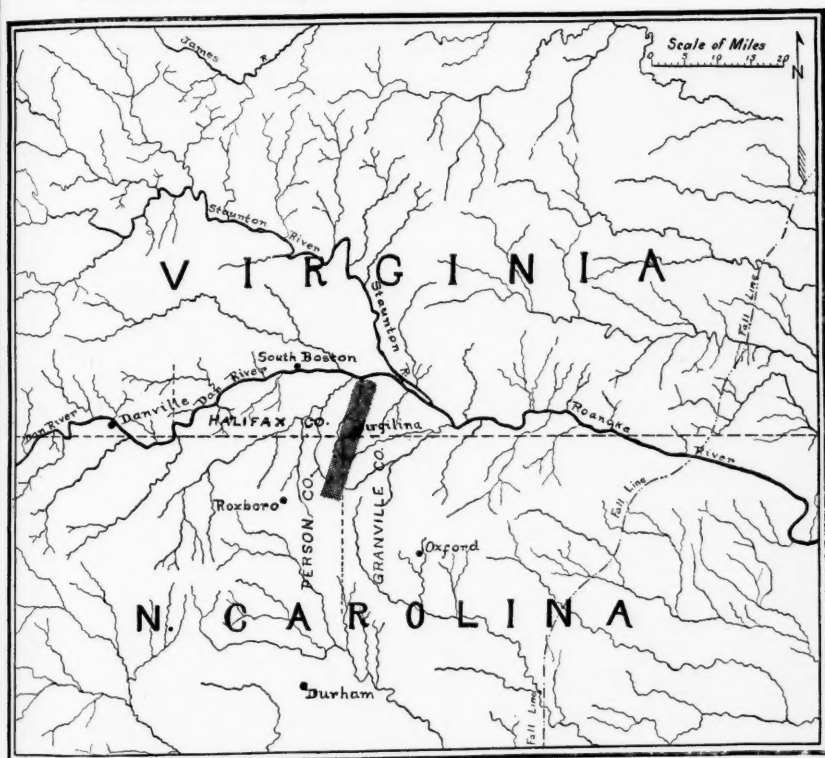


FIGURE 1.—*Virgilina Copper District, Virginia and North Carolina.*
Copper district indicated by shaded area.

Natural outcrops of the rock are by no means common and are seldom more than 3 feet high, forming sharp and narrow spurs or reefs, which persist for only short distances. The numerous shafts sunk over the greater part of the belt to depths of 40 to 500 feet afford excellent opportunity for exceptional collections of the rocks and ores.

The covering of loose, decayed surface rock and soil is very thin, and the moderately fresh and firm rock is encountered at slight depths beneath the surface.

At the mine openings some alteration in the vein constituents is indicated to the entire depth of the workings, 400 to 500 feet. This is shown in the case of the sulphide ores, which in several places are slightly changed by the percolating carbonated waters to the green copper carbonate (malachite) found slightly staining the vein material and the unaltered ores. The rocks taken at these depths are of the same characteristic green color, and the thin-sections indicate the same amounts of chlorite and epidote as those from the shallow depths. As developed, both macroscopically and microscopically, the rocks collected at the various depths are indistinguishable. This is also shown in the dumps at the mine openings.

The microscope reveals, as elsewhere shown, the igneous origin of the rocks; but, with few exceptions, the rocks do not entirely indicate their true igneous nature in the field. They are prevailingly finely laminated and schistose in structure, having the general characteristic features of a soft, green to purple colored schist. A number of sections showed the prevailing strike of the schistosity to be north 10 to 20 degrees east and an eastward dip of 70 to 80 degrees.

The change in these rocks is clearly the result primarily of the processes of metamorphism active while the rocks were deeply buried. At a subsequent date, when the rocks were brought near the surface, they were further changed by weathering. The mineral products resulting from the alteration are strongly in evidence. Epidotization and chloritization are manifested on a considerable scale.

The greenstones are cut in several places by diabase dikes of later geological age. One of these dikes, 12 feet wide, is exposed in the Blue Wing mine at the 100-foot level, where it is observed to cut across the schistosity of the rocks. These dikes are described in the reports of the North Carolina Survey as being quite numerous in parts of Granville and Person coun-

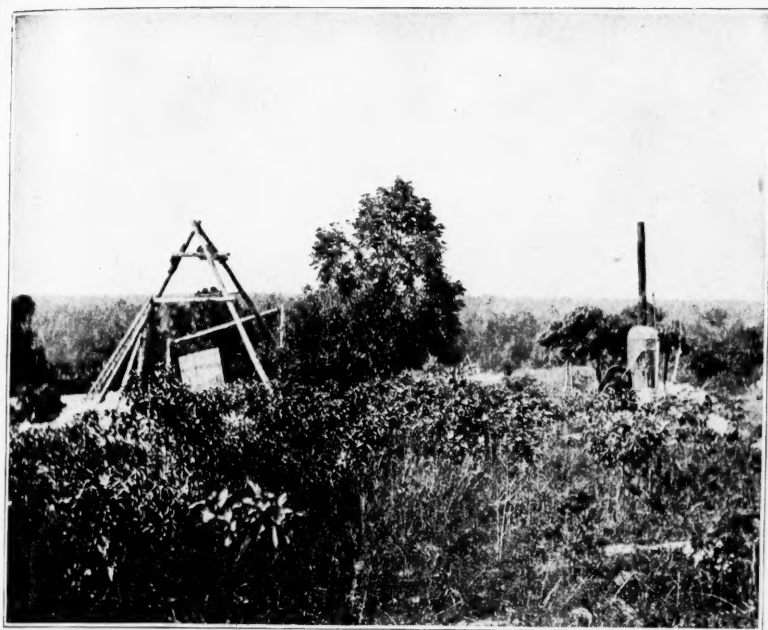
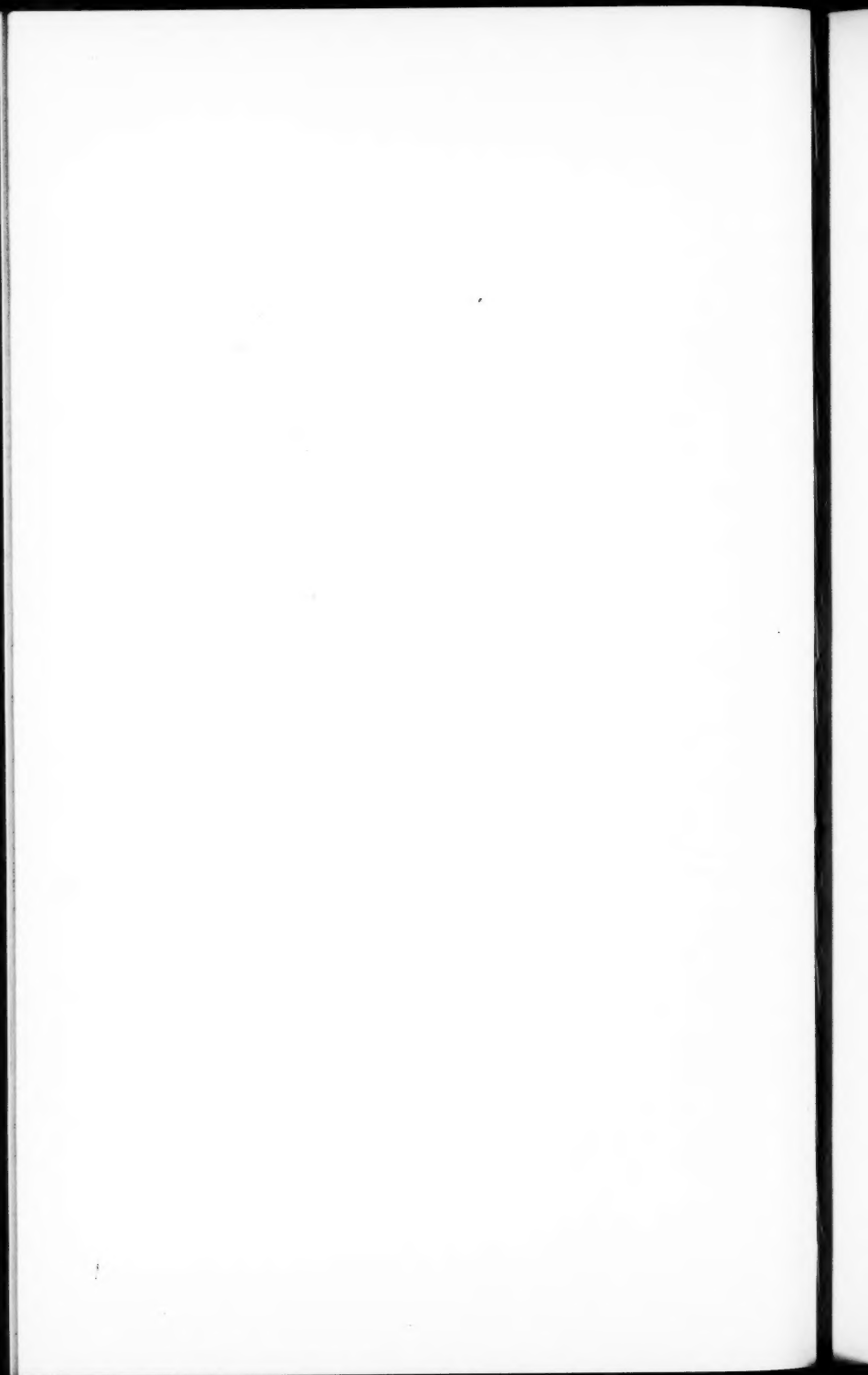


FIGURE 1—SHAFT NUMBER 3



FIGURE 2—SHAFT NUMBER 4

HIGH HILL COPPER MINES, HALIFAX COUNTY, VIRGINIA.



ties. Faulted and slickensided surfaces are in evidence at some of the mine openings.

The rocks are further cut by numerous irregular quartz veins, which contain the workable copper ores. The veins are traced for a mile or more in length on the surface, and in most cases they are more or less parallel, partially overlapping at the ends, and trending north 5 to 10 degrees east. They are grouped by Weed¹ as true fissure veins, lenticular in shape, though connecting, crossing at times the schistosity of the rocks and at others parallel to it. The surface over most of the district is much littered with white quartz fragments derived from the disintegration of the veins.

PETROGRAPHY.

Macroscopic Descriptions.

A pronounced schistose structure prevails, and only in a few places do the rocks appear like massive eruptives in the field. The degree of schistosity varies from the thin banding of a gneiss to the typical foliation of micaceous schists. The very finely banded structure is more characteristic of the purple-colored rocks. The rocks vary in color from some shade of medium to dark green (the prevailing color) to a slate purple.

The rocks are aphanitic in texture, displaying at times a distinct porphyritic structure in the massive phases, which becomes more apparent under the microscope. The massive phases of the rock are indicated at several places within a few miles to the north and south of the town of Virgilina. With one exception, this type is prevailingly dark in color, showing on close examination a mingling of green and purplish shades, with the greenish tint so predominant that the rock appears dark green on first glance. Both the characteristic chlorite and epidote shades of green are contrasted at times in the same specimen. On a freshly broken surface the fracture is conchoidal to subconchoidal, with a more or less waxy luster.

Approximately half a mile south of Virgilina a shallow

¹ Trans. Amer. Inst. Min. Engrs., 1901, vol. xxx, p. 452.

opening (Cornfield) is made, showing the massive rock in its least altered condition (analysis I). The rock is porphyritic in structure and the color is a medium dark-purplish shade, which contrasts with the surrounding more altered green schistose rock.

Epidote of the usual pistachio-green color enters largely in places into the composition of the rocks, and it is mixed locally in considerable proportion with white quartz as a vein mineral. The schistose greenstone is easily scratched with the knife, and suggests approximately the same degree of hardness as that of ordinary clay slate.

At the Copper World mine, $6\frac{1}{2}$ miles south of Virgilina, in the Carolina portion of the belt, a partially loose-textured, fine-grained, purple rock is mixed with the surrounding green schists. The material bears every resemblance to a tuff,¹ and is streaked in places by the characteristic actinolite shade of green due to alteration, and contains inclosures of a dark-colored massive material, usually of small but varying dimensions and partially rounded in outline. The fragmental or clastic nature of the mass is plainly visible. The microscope confirms the clastic nature of this rock and shows that it is composed of fragments of igneous rocks of the same character and composition as the igneous rocks of the district. Microscopic study also indicates the presence of similar clastic material at a number of other points in the district.

No trace of the amygdaloidal structure, so characteristic of the South Mountain and Lake Superior basic greenstone areas, has been observed in the Virgilina rock.

Copper-bearing rocks
Microscopy of the Rocks.

The rocks vary in texture from dense aphanitic to medium fine-grained, with the porphyritic structure shown usually in the massive types. The original minerals are entirely altered to secondary minerals in many of the sections, but, with few exceptions, some trace of the original outline of the feldspar con-

¹ See Weed, W. H., op. cit.

stituent is shown and more or less of the original rock texture preserved. While this is true for the feldspar constituent, the original bisilicate constituent is completely altered in every slide studied, without any indication as to what the mineral originally was. Considering the age and composition of the rocks, it seems remarkable that any of the original minerals or structures should be preserved at present. When shown, the texture varies from a partial microphitic to microlitic in the non-porphyrific types, with the same variation and composition of the groundmass in the porphyritic rocks denoted.

The constituents present are plagioclase, bluish to light green amphibole, chlorite, epidote, zoisite, calcite, iron oxide (partly magnetite), quartz, and apatite. Of these only the feldspar, a part of the iron oxide (magnetite), and apatite are original. Both chlorite and epidote, intimately associated with more or less hornblende, are abundantly developed in most of the sections, sometimes one, sometimes the other predominating; but the two are at all times intimately connected.

In the porphyritic and non-porphyrific types the feldspar is present as lath-shaped crystals, showing the broad twinning lamellæ of the albite type. Twinning after the Carlsbad law was observed in several instances. In the ground mass of the porphyritic rocks and in the fine-textured non-porphyrific types the feldspars are microlitic, with the boundaries less sharp and well defined than for the lath-shaped feldspars, and the twinning is not at all or only slightly indicated. Sometimes the feldspar grouping is suggestive of the sheaf-like arrangement described by Clements¹ in similar volcanic rocks of the Hemlock formation of Lake Superior. Poikilitic texture is well developed in many of the larger feldspar laths.

Feldspar is the only porphyritically developed mineral, and it consists of fairly large, stout laths of broadly striated plagioclase, with maximum extinction angles measured on the twinning planes of 14 to 20 degrees, which would apparently indicate an acid plagioclase, probably near oligoclase.

¹ Monograph No. xxxvi, U. S. Geol. Survey, 1899, p. 99.

The feldspars of both the groundmass and phenocrysts are frequently fractured and mashed, showing the effects of pressure, which is seen to best advantage in the schistose rocks.

Not a trace of original hornblende was positively identified in any of the sections. Amphibole is fairly abundant in most of the slides as a secondary product, and as such is usually light green to slight bluish green in color and as fibrous and frayed out masses. A more common occurrence, perhaps, is as a felt of actinolite needles admixed with the other constituents, particularly chlorite, epidote, and iron oxide. The needles are very long and slender and are frequently much curved and bent. The pleochroism of the actinolite is usually quite strong.

No trace of either augite or olivine was indicated in any of the slides. On account of the greatly altered condition of the rocks, it would not be safe to state that they were not present as original constituents.

Chlorite is a constant and abundant constituent of the rocks, but is variable in amount, and presents the usual occurrence for such rocks. A striking feature is the intimately associated grains and plates of epidote distributed through the chloritic mass in a manner to indicate the simultaneous development of the two minerals, a characteristic occurrence in some of the Lake Superior greenstones described by Williams.¹ Clements² has shown that in some of the basic volcanics of the Hemlock formation the great abundance of chlorite in some sections is more than could result from the alteration of that amount of the original bisilicate present, and points out that it is derived in part from the altered glassy base. This explanation is likely applicable to some of the sections of the Virgilina rocks, since the amount of chlorite is in excess of the original bisilicate, and is probably a derived product in part from an altered glassy base.

Epidote in the form of small and large irregular grains and

¹ Bulletin No. 62, U. S. Geol. Survey, 1890, p. 56 et seq.

² Monograph No. XXXVI, U. S. Geol. Survey, 1899, p. 101.

plates is abundantly present, closely associated with chlorite and amphibole. It varies in color from deep yellow to nearly colorless grains, with high single and double refraction, and showing strong pleochroism in the colored individuals. The somewhat idiomorphic plates show the $M(001)$ and $T(100)$ cleavages in their usual development.

Zoisite, when identified, was closely intergrown with the epidote, forming an epidote-zoisite aggregate, the individuals of which are differentiated by their contrasted double refraction.

Iron oxide is extremely abundant in portions of some of the sections, and to some degree in all. It is not all magnetite, as indicated by the red color of much of it. It is separated from the other constituents of the powdered rock by means of the magnet. It occurs as minute grains and crystals, and is in part primary and in part secondary. It is so abundant in some sections as to entirely mask some of the other more important constituents. Its secondary nature is frequently shown in its peripheral position surrounding the iron-bearing constituent from which it was derived.

The remaining minerals occurring in the rocks present no noteworthy features.

In the thin-sections of the purple-colored slaty rocks of the Copper World, Durgy, and Yancey mines and the "Slate Vein," in the Carolina portion of the belt, and probably the fissile greenstone from the Halifax Copper mine, in Virginia, there is strong evidence for regarding the rocks as clastic volcanics. The evidence is less plain in some sections than in others, on account of the extreme alteration having destroyed nearly all trace of the rock structure. When the texture is not entirely destroyed the microscope shows a clastic composed of igneous fragments similar in all respects to the true igneous rocks of the district.¹

¹ Through the kindness of Professor J. Morgan Clements, of the University of Wisconsin, I have been able to examine and compare the slides of the similar volcanic rocks of the Lake Superior region, and the similarity, as remarked by Professor Clements, is strikingly close to the rocks of the Virgilina district.

Professor Clements very kindly examined the thin-sections of the Virginia-

The microscopic study entirely fails to indicate what the original characterizing bisilicate component was in these rocks—whether augite or hornblende, or both, with possible biotite and olivine. We are in doubt, therefore, as to whether the rocks were originally augite or hornblende andesites.

Chemical Analyses. of copper-bearing rocks

Six analyses of the Virgilina greenstones, four complete (analyses I–V, inclusive) and two partial (VI and VII), were made by the writer in the chemical laboratory of Denison University.¹ These are compared with analyses of so-called greenstones (Catoclin schist) of the Catoclin belt of northern Virginia (analysis VIII) and with those of the well known Marquette and Negaunee districts of Michigan (analyses XIII and XIV). Also analyses I and II, representing the freshest material, are compared with analyses of andesites from Colorado (analyses IX and XII) and Maine (analysis XI).

A cursory examination of the analyses is sufficient to indicate the andesitic character of the rocks, with an advanced stage of alteration shown in IV, V, VI, and VII. Furthermore, the ratio of the SiO_2 to the base-forming elements in I and II, the least altered material, suggests an intermediate rather than an acid or basic andesite. The prevailing low SiO_2 in the remaining analyses (IV, V, VI, and VII) is explained on the basis of advanced alteration, since the rocks yielding these results were the most altered and were highly schistose in structure. Other apparent irregularities in the analyses are likewise explained on the same basis, since the greatest irregularities are indicated in the analysis of the most

North Carolina rocks and the accompanying hand specimens here described, and in a personal memorandum to the writer stated that the rocks were igneous and of an andesite character, confirming the writer's study of the material; further, that the evidence was strong for regarding some of the volcanics as clastics composed of fragments of basic or intermediate igneous rocks similar to the igneous rocks of the district. He says: "I find they [Virginia-North Carolina rocks] are very similar to the greenstones which form so important a part of the Archæan and Algonkian of the Lake Superior region."

¹ I am indebted to Professor W. Blair Clark, of Denison University, for kindly placing at my disposal the facilities for making the analyses.

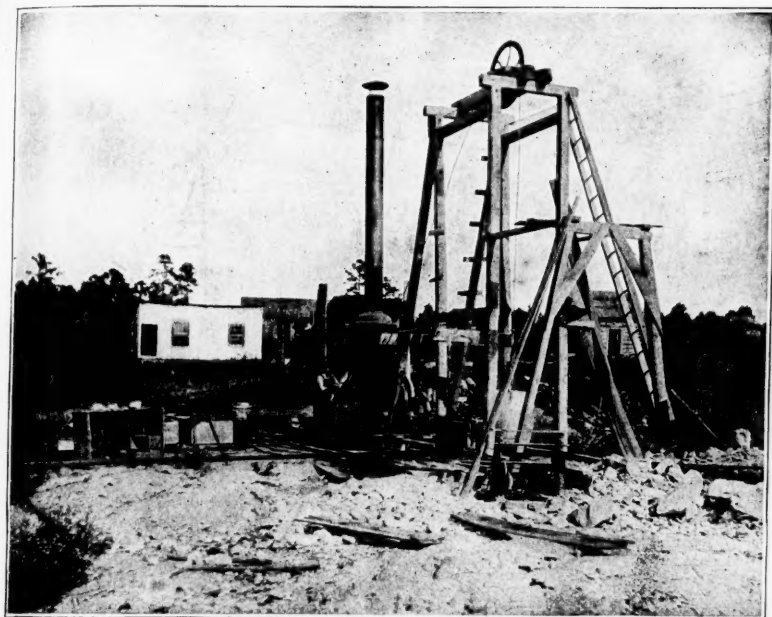


FIGURE 1—SHAFT NUMBER 1—YANCEY MINE

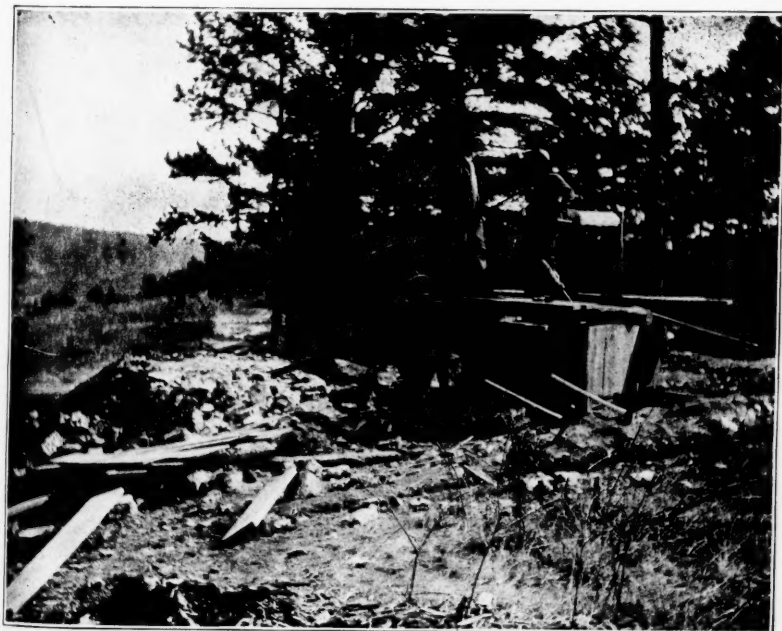
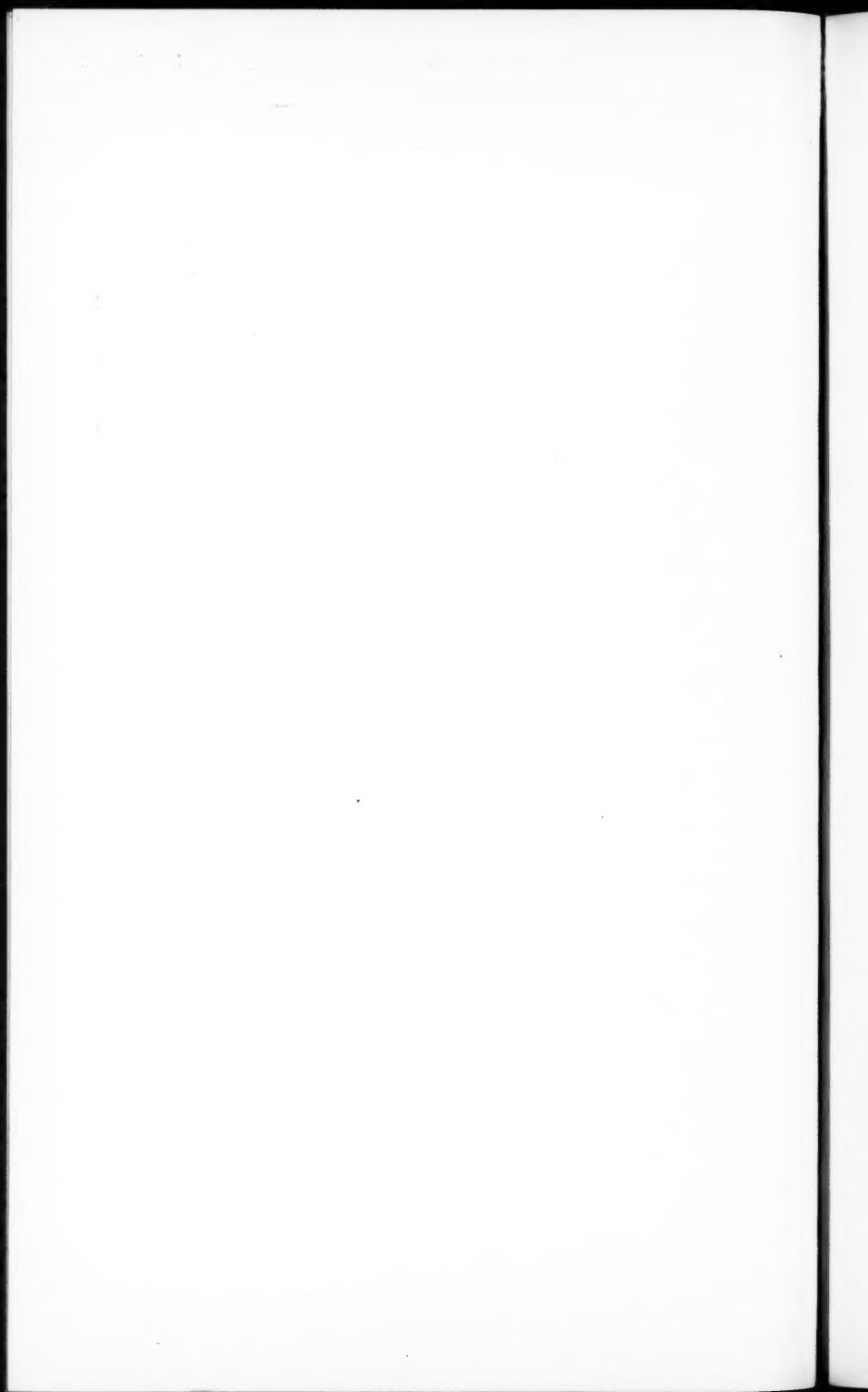


FIGURE 2—FOURTH OF JULY SHAFT

COPPER MINES, PERSON COUNTY, NORTH CAROLINA.



altered specimens. To what extent the ore-bearing solutions have aided in the alteration it is not possible to say, but that the change has resulted in part from such action is doubtless shown in the metalliferous veins of the district.

When I, II, and III, analyses of the least altered rock, are compared with analyses of recognized andesites occurring elsewhere, no marked differences in the essential constituents are shown.

Higher SiO_2 and Al_2O_3 and lower Fe_2O_3 , FeO , CaO , and MgO in the Virgilina rocks than for the similar rocks in the Catoctin belt are noted. Na_2O is approximately the same for the two rocks, with increased K_2O shown in the Catoctin andesite. The Catoctin andesite is characterized by very high iron oxide and correspondingly low SiO_2 and clearly represents the basic type of andesite, which readily accounts for the apparent variations shown in the comparison with the Virgilina rock.

Comparing the analyses of the Virginia-North Carolina rocks with those of andesites from Colorado (analysis IX, XI, and XII) and Maine (analysis X), the differences are by no means so great as shown in the Catoctin andesite, but, on the contrary, the figures are strikingly close and uniform for rocks occurring in areas so widely separated.

Analyses XIII and XIV are of typical greenstones from the Michigan area derived, as Williams states, from the igneous rock type, diabase. A comparison of these two analyses with the average of I and II given in column III indicates at a glance those differences shown in chemical composition which distinguish a diabase from an andesite.

So far, then, as chemical analyses are trustworthy, the percentage ratios of the various constituents in the Virginia-North Carolina rocks, as indicated in I and II, and their average III, are those of andesite. Passing, then, from the least to the most altered phases of the rocks, the change is observed to consist largely in the increase in the amount of chlorite, as clearly manifested in the assumption of water, hydration; and also in increased Al_2O_3 and MgO . A similar change in the

CHEMICAL

	I.	II.	III.	IV.	V.	VI.	VII.
SiO ₂ -----	64.12	62.32	63.22	51.34	48.20	46.45	49.51
TiO ₂ -----	Trace.	0.06	0.03	0.38	0.24	Trace.	0.57
Al ₂ O ₃ -----	16.32	15.79	16.05	20.07	22.10	13.79	22.42
Fe ₂ O ₃ -----	6.72	3.57	5.15	7.03	7.61	7.60	10.03
FeO-----	1.38	4.61	2.49	4.03	3.95	6.41	2.42
MnO-----	0.64	0.35	0.49	0.38	0.35	Trace.	0.42
CaO-----	3.49	3.65	3.57	2.83	8.86	10.13	7.68
MgO-----	0.33	2.53	1.43	4.18	0.86	9.81	2.81
BaO-----	-----	-----	-----	-----	-----	-----	-----
SrO-----	-----	-----	-----	-----	-----	-----	-----
Na ₂ O-----	6.22	4.51	5.37	1.83	4.90	Undet.	Undet.
K ₂ O-----	0.53	0.76	0.64	5.53	1.16		
Li ₂ O-----	-----	-----	-----	-----	-----	-----	-----
H ₂ O-----	0.34	1.89	1.11	2.90	2.31	2.66	3.41
P ₂ O ₅ -----	Undet.	Undet.	Undet.	Undet.	Undet.	Undet.	Undet.
SO ₃ -----	-----	-----	-----	-----	-----	-----	-----
CO ₂ -----	None.	None.	None.	None.	None.	2.27	0.90
V ₂ O ₅ -----	-----	-----	-----	-----	-----	-----	-----
	100.09	100.04	99.55	100.50	100.54	-----	-----

I. Andesite, dark purplish gray, massive and slightly porphyritic in texture, 0.5 mile south of Virgilina, Granville county, North Carolina; Cornfield opening. Analysis by Thomas L. Watson.

II. Dark massive greenstone; Overby opening. Analysis by Thomas L. Watson.

III. Average of I and II.

IV. Bright schistose greenstone, Blue Wing mine, 3 miles south of Virgilina, Granville county, North Carolina. Analysis by Thomas L. Watson.

V. Bright schistose greenstone, Fourth of July mine, 2.5 miles south of Virgilina, Granville county, North Carolina. Analysis by Thomas L. Watson.

VI. Bright Schistose greenstone, Anaconda mine, 1.5 miles south of Virgilina, Halifax county, Virginia. Analysis by Thomas L. Watson.

VII. Partially decayed schistose greenstone from same locality as VI. Analysis by Thomas L. Watson.

VIII. Andesite, 3.5 miles east of Front Royal, Virginia. Analysis by George Steiger, Bulletin 168, U. S. Geological Survey, 1900, page 51; described by Keith, Fourteenth Annual Report, U. S. Geological Survey, page 305.

IX. Hornblende andesite, summit of southeast spur of Galena mountain, above Big 10 claim, near Silverton, Colorado. Frank R. Van Horn, Bulletin of the Geological Society of America, 1900, volume 12, page 8.

ANALYSES.

VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
5 1.08	61.36	61.40	61.45	61.58	43.80	44.49	50.20	61.37
2.67	Undet.	0.79	2.80	0.49	Undet.	Undet.	-----	0.60
11.37	16.56	16.59	15.07	16 96	16.08	16.37	15.43	15.41
11.17	3.44	2.13	4.46	1.75	9.47	5.07	-----	3.15
5.64	2.93	3.05	1.18	2.85	10.50	5.50	13.79	3.89
0.22	Undet.	0.13	None.	Trace.	-----	-----	-----	0.47
5.20	4.56	6.17	5.37	6.28	7.81	7.94	5.47	4.42
3.96	0.85	2.73	3.02	3.67	6.54	7.50	8.62	3.48
-----	-----	0.02	-----	0.03	-----	-----	-----	0.08
-----	-----	Trace?	-----	Trace.	-----	-----	-----	Trace.
{ 5.54	6.86	3.83	4.00	3.94	1.96	2.59	4.75	3.76
1.50	1.30	1.34	1.22	1.28	0.34	0.56	-----	0.34
-----	-----	Trace.	0.05	Trace.	-----	-----	-----	-----
1.50	1.55	1.70	1.23	1.30	3.99	4.99	1.74	2.99
-----	-----	0.20	Trace.	0.22	-----	-----	-----	0.08
-----	-----	-----	0.29	-----	-----	-----	-----	-----
0.39	Trace.	None.	-----	-----	0.08	5.38	-----	-----
-----	-----	0.02	-----	-----	-----	-----	-----	-----
100.24	99.41	100.10	100.14	100.35	100.57	100.39	100.00	100.04

X. Andesite, Edmund's Hill, Aroostook county, Maine. Analysis by W. F. Hillebrand. Herbert E. Gregory, *American Journal of Science*, 1899, volume viii, page 365.

XI. Pyroxene andesite, Agate creek, Yellowstone National park. Analysis by Whitfield, *Bulletin 168, U. S. Geological Survey*, 1900, page 108.

XII. Hornblende andesite, Mount Shasta, California. Analysis by H. N. Stokes, *Bulletin 168, U. S. Geological Survey*, 1900, page 176.

XIII. Dark massive greenstone, Lower Quinnesec falls, Michigan. Analysis by R. B. Riggs. G. H. Williams, *Bulletin 62, U. S. Geological Survey*, 1890, page 91.

XIV. Dark schistose greenstone, forming a band in XIII. Analysis by R. B. Riggs. G. H. Williams, *Bulletin 62, U. S. Geological Survey*, 1890, page 91.

XV. Greenstone, summit of ridge at Cliff mine. Quoted by A. C. Lane, *Geological Report on Isle Royale, Michigan, Geological Survey of Michigan*, 1898-1897, volume vi, page 215.

XVI. Meta-andesite, 1.5 miles northward from Jenny Lind. Analysis by W. F. Hillebrand. *Bulletin 168, U. S. Geological Survey*, 1900, page 203.

rocks of the greenstone area of Michigan has been emphasized by Williams. A second and no less important change in the Virginia-North Carolina rocks is the increased amount of epidote in the much-altered phases of the rocks, a fact indicated microscopically as well as in the field, and further confirmed chemically in the greatly increased amounts of CaO in the analyses of the altered over those of the fresher rocks.

Attention is finally directed to the alkalis' ratio in these rocks, in which it is observed that K_2O is reduced to practically a minimum, while the Na_2O is proportionately increased. The constant presence of TiO_2 and MnO in the analyses is a noteworthy feature.

EVIDENCES OF ERUPTIVE CHARACTER.

Field Evidence.

The field evidence that the schistose rocks here studied are of igneous origin is not entirely lacking when the belt as a whole is considered. While the rocks are prevailingly schistose or foliated, and in places thinly fissile, areas of much altered, though massive, rocks of the same color and texture are met in a number of places, and are most satisfactorily explained as igneous in origin. This alteration is the result of dynamic metamorphism accompanied by much chemical action, consisting largely in the abundant development of chlorite and epidote. A similar change has been observed in the greenstone areas of Michigan¹ and South Mountain,² Pennsylvania. In most cases where the original character is entirely lost and a perfect secondary schistosity assumed it becomes necessary to resort to the microscope to determine their nature.

In the massive and least altered phases of the rock the porphyritic structure is apparent. The porphyritic constituent measures less than one millimeter in size, and is distributed through an aphanitic groundmass of uniformly green and purple colors. The porphyritic structure is more strikingly shown

¹ Williams, G. H., Bulletin No. 62, U. S. Geol. Survey, 1890, pp. 192-217.

² Bascom, F., Bulletin No. 136, U. S. Geol. Survey, 1896, p. 25.

in some of the thin sections under the microscope than in the hand specimens. In such cases the porphyritic mineral consists principally of a well striated plagioclase.

The prevailing fineness of grain of these rocks, which is equally characteristic of the freshest specimens as for the most altered material, and the associated tuffs or clastic volcanics suggests solidification at the surface.

The weathered outcrops afford, as a rule, only slight indication of an igneous mass, although at one point a few miles to the south of Virgilina, in Carolina, the spheroidal type of weathering was observed. Since the rocks are usually no longer massive, but instead are highly schistose in structure, the weathered surfaces for structural reasons would be expected to more closely simulate those of sedimentary masses.

The extension of the belt as traced from the rock outcrops for many miles in an approximately north-south direction, with comparatively a very narrow cross-section, is certainly suggestive. Their weight, color, texture, and not unfrequent massive structure are properties more characteristic of igneous than of sedimentary rocks.

Massive granites and granitic gneisses, and in places dikes of diabase, limit the area on the east and west sides. In several instances the diabase is found cutting the rocks of the greenstone area. Some evidence, both field and microscopic, is at hand for regarding some of the rocks at several places in the belt as altered andesite tuffs or clastics composed of fragments of the igneous rock.¹ The study has not been sufficiently extended, however, if, indeed, it were possible, to differentiate the clastic volcanics (tuffs) from the direct igneous masses of the area.

Microscopical Evidence.

The evidence of the igneous origin of these rocks is not entirely that of field relations, but is derived largely from microscopic structure, mineral and chemical composition. In

¹ Weed, op. cit.

many instances the thin-sections show both stout and acicular forms of striated feldspar partially or wholly preserved, embedded in a fine-grained groundmass composed principally of green chlorite and hornblende, epidote, altered feldspar and iron oxide. This arrangement is not confined to the massive and least altered forms of the rocks, but is indicated to some degree in the partial skeleton outlines of some of the original minerals in several slides of the perfectly schistose rocks. In many cases chemical and structural metamorphism have progressed so far that all trace of the original structure, as well as that of every original mineral, has been destroyed.

The occurrence of lath-shaped polysynthetically twinned crystals of plagioclase which appears to have formed an essential constituent of the rocks is characteristic of rocks of igneous origin. Furthermore, the microphitic and poikilitic structures of the feldspars of some of the rocks in thin-section under the microscope are common only to igneous masses. The structures bear certain striking resemblances to similar rocks of igneous origin described by Williams¹ and Clements² from the Lake Superior region. Professor Williams³ reproduces a photomicrograph of a thin-section of one of the rocks showing this structure from the Negaunee district, which has its analogue in several sections of the Virgilina rocks.

The minerals composing the rocks, which are chiefly secondary, are those which would result from chemical and structural metamorphism of an original igneous rock of basic or intermediate composition.

While, as already stated, in most instances all trace of the original minerals in the rocks is lost or destroyed, in some sections enough remains to tell with some degree of certainty what their original essential minerals were.

The analyses of these rocks given in the table on page 112

¹ Williams, G. H., Bulletin No. 62, U. S. Geol. Survey, 1890.

² Clements, J. Morgan, Jour. of Geology, 1895, Vol. III, pp. 801-822; Monograph, No. XXXVI, U. S. Geol. Survey, pp. 98-103.

³ Williams, G. H., op. cit., p. 226, plate X, figure 2.

confirm their igneous character. When compared with similar analyses of well known igneous rocks of a certain type from widely separated localities, fairly close agreement is shown in the essential chemical features. Knowing, therefore, the greatly altered condition of the bulk of the rocks in the area, such differences as are brought out in the table of analyses are readily explained on the basis of chemical and physical metamorphism.

Chemical Evidence.

The chemical analyses of these rocks have been previously discussed in this paper—pages 112–113. The close conformity in composition of the rocks (the least altered ones), as there indicated, with that of andesites from well known but widely separated localities is certainly indicative of igneous origin. Their uniform composition is in contrast with that of a series of clastic rocks, where, as shown by Rosenbusch,¹ the chemical proportions are largely accidental. The microscopical study fully confirms the chemical evidence favoring the igneous origin of these rocks.

Comparison with other Areas.

Scattered areas of ancient volcanic rocks have been recognized at various localities along the Atlantic coast by geologists, extending from New Brunswick through Maine, New Hampshire, Massachusetts, Pennsylvania, and Maryland into northern Virginia, the Carolinas, Georgia² and Alabama. Some of the so-called sedimentary areas of the northern Atlantic coast of the earlier geologists are now regarded as altered volcanic rocks.³

Areas of such volcanics have been described from eastern

¹ Zur Auffassung der Chemischen Natur des Grundgebirges, Tschermak's Min. u. Petrog. Mitth. 1891, Vol. XII, pp. 49–61.

² G. H. Williams discusses this subject in the 15th Ann. Report, U. S. Geol. Survey, 1895, pp. 663–664.

³ For a statement of the distribution of the volcanic rocks on the Atlantic coast, see Williams, Jour. Geology, 1894, II, 1–31.

Canada,¹ by Bailey, Matthew, Ellis, and Bell. In New England² Wadsworth, Diller, Shaler, Bayley, G. O. Smith, H. S. Williams, and Gregory have described similar areas in Massachusetts and Maine. Other similar areas are well known in Pennsylvania, Maryland, and Virginia through the investigations of G. H. Williams,³ Keith,⁴ and Bascom.⁵ In the Lake Superior region⁶ they have been long known through the contributions principally of Irving, Van Hise, the Winchells, Clements, Bayley, Wadsworth, Williams, and Grant.

Through the studies of Clements and Brooks areas of greenstone schists, similar to those of the Lake Superior region, and derived from an original basic igneous rock of pre-Cambrian age, have been identified in the crystalline area of Alabama.⁷

The rock types indicated in these areas vary from acid to basic volcanics in composition, according to locality, and are represented principally by such rocks as rhyolite, andesite, diabase, diorite, gabbro, and their associated tuff deposits.

From the descriptions, the rocks of the Virgilina district are closely similar in many essential features to the corresponding altered phases of the Catoctin and South Mountain areas in Virginia, Maryland, and Pennsylvania, and certain ones of the famous greenstones from the Lake Superior region. When the altered rocks, greenstones, of the various areas are traced by

¹ Ann. Report Canadian Geol. Survey, 1877-'8 D D, 1879-80 D, 1889-'90 F, 1891.

² Mus. Comp. Zool. Bull., Vol. V, p. 282; *ibid.*, Vol. VII, pp. 166-187, 1881; A. J. S., 1886, Vol. XXXII, p. 40; 8th Ann. Rept. U. S. G. S., pt. 2, p. 1043; A. J. S., 1899, Vol. VIII, p. 359; Bull. No. 165, U. S. G. S., 1900, 212 pp.

³ A. J. S., 1892, XLIV, 482-496; Jour. Geology, 1894, II, 1-31.

⁴ 14th Ann. Rept. U. S. G. S., 1894, pp. 285-395; Am. Geol., 1892, X, 365; Bull. G. S. A., II, 156, 163.

⁵ Bull. No. 136, U. S. G. S., 124 pp.

⁶ The literature is scattered through annual reports, monographs, and bulletins of the U. S. Geological Survey and the state reports of the surveys of Minnesota, Wisconsin, and Michigan.

⁷ Geol. Survey of Alabama, Bulletin No. 5, 1896, pp. 84-96, 120-197.

means of chemical and microscopical study to the original rock type, the differences become more apparent. This difference is that which distinguishes in the original rock an andesite from a diabase, diorite, gabbro, et cetera; but, as already stated, the altered rock derived from these several types is closely similar.

Sufficient study of the ancient volcanic rocks occurring to the southwest of the Virgilina area, in North Carolina, is lacking on which to base specific comparisons. That they are altered volcanic rocks of great age, comprising both acid and basic types, is established, but the exact mineral and chemical composition, denoting the original types from which they are derived, is yet to be investigated. Megascopic descriptions and the field relations of many of the basic types indicate their striking similarity to those of the Virgilina district.

As developed from the chemical and microscopic study of the rocks of the Virgilina district, the present much altered rock, greenstone, clearly indicates its derivation from an original andesite of an intermediate basic type as contrasted with the similar Catoctin schist or greenstone, which from Keith's¹ description, is derived from a more basic andesite, diabase, or basalt.

According to Keith, the rocks of the Catoctin area are igneous in origin and represent probably two different flows—the upper, basaltic, and the lower, dioritic. In general the rocks are much altered through dynamic metamorphism and secular decay and now largely form greenish epidotic and chloritic schists, designated by Keith as the Catoctin schist. The fine-grained varieties are composed of quartz, plagioclase, epidote, magnetite, and chlorite. In the coarse-grained types the original nature of the rock is well indicated. The ophitic arrangement of the coarse feldspars is definitely marked. The additional minerals in the coarse rocks are calcite, ilmenite, skeleton olivine, biotite, hematite, and, in a few instances, hornblende. The alteration products, chlorite and epidote, are abundant and characteristic. An analysis of the fresh rock by

¹ 14th Ann. Rept. U. S. G. S., 1894, p. 304 et seq.

George Steiger is shown in column VIII of the table of analyses, on pages 112-113.

The South Mountain area is shown by Williams¹ and Bascom² to consist of the acid volcanic rhyolite and the basic types, diabase and basalt, the latter yielding on alteration the greenstones of the region. Bascom³ further describes the basic types of this region as holocrystalline, effusive, plagioclase-augite rocks, with or without olivine, the essential characteristics of the diabase group.

After establishing the igneous origin of the greenstones of the Menominee and Marquette districts of Michigan, Williams⁴ shows the different rock types to have been olivine-gabbro, gabbro, diabase, diabase-porphyry, glassy diabase and melaphyre, and tuffs, with the two districts limited on their north and south sides by an acid series consisting of granite, granite-porphyry, and quartz-porphyry.

The original mineral constituents of these rocks are described by Williams⁵ as labradorite, quartz, biotite, hornblende, diallage, augite, olivine, zircon, apatite, sphene, ilmenite, and magnetite. The secondary minerals produced by metamorphism and weathering are albite, saussurite, zoisite, quartz, hornblende, epidote, chlorite, biotite, talc, serpentine, carbonates, iron oxides and pyrite.⁶

Van Hise and Clements regard the greenstone schists of the Crystal Falls iron-bearing district as altered diabase, diabase-porphyry, and gabbro.⁷ Clements⁸ has shown the derivation of the greenstones of the Hemlock formation to be from original basaltic and andesitic rocks.

¹ Op. cit.

² Op. cit.

³ Ibid., p. 69.

⁴ Bull. U. S. Geol. Survey, No. 62, pp. 197-199.

⁵ Ibid., pp. 199, 200.

⁶ Ibid., pp. 213, 214.

⁷ Mono. U. S. Geol. Survey, vol. xxxvi, pp. 484-486; *ibid.*, vol. xxviii, pp. 203-208.

⁸ Ibid., vol. xxxvi, pp. 95-148.

The evidence here adduced from the descriptions of the rocks of the several areas indicates the striking fact that the present altered rock, greenstone, is remarkably similar for the several districts, but when, through chemical and microscopic means, they are traced to the original rock, distinct differentiation, such as distinguishes the various basic igneous types from each other, is shown. Moreover, not only is this striking similarity indicated in the altered rock in each instance, but the processes involved in producing the alteration have been uniformly alike. The alteration has been one of structural and chemical metamorphism, resulting in the formation of abundant chlorite and epidote and smaller amounts of other secondary minerals and the accompanying secondary schistose structure.

ORE DEPOSITS OF THE DISTRICT.¹

The deposits of the immediate district are copper, with those of workable iron ore reported from other portions of the same counties. Copper prospecting in the district dates back forty or fifty years. The Gillis copper mine was opened in 1856,² exposing a large body of copper glance. Systematic work is of recent date, however.

The ore occurs mostly in quartzose veins, and to a limited extent as finely divided particles disseminated through the rocks in places. The workable ore is confined entirely to the veins. The vein stone consists principally of quartz with considerable calcite and epidote mixed locally. The altered country rock, greenstone, is intimately mixed with the quartz and calcite as thin lenses and stringers, which impart, in places, a banded structure to the vein. The included portions of the altered rock vary from mere films and dark streaks in the quartz to a preponderance of the schist with quartz infiltrated between the layers. The quartz is further frequently encased by layers of the schist wrapped around it.

¹ For a detailed description of the individual mines and the general features of the belt as a whole, see W. H. Weed, *Trans. Amer. Inst. Min. Engrs.*, 1901, vol. xxx, pp. 449-504. An earlier account is given by Geo. B. Hanna in *Ores of North Carolina*, 1888, pp. 214-220.

² Emmons, E., *Geol. Survey of North Carolina*, 1856, p. 344.

The workable ore comprises glance and bornite mixed with the green carbonate, malachite—an alteration product from the original sulphides. A considerable sprinkling of the red oxide and native copper are seen in places. Genth and Kerr¹ mention the following copper minerals occurring in Person and Granville counties: chalcopyrite, chalcocite, malachite, chrysocolla, cuprite, and native copper. Chalcopyrite and pyrite are almost entirely absent from these veins. They were observed in largest amount at several shafts being opened on the High Hill property in Virginia at the time of the writer's visit.

So far as examined, the ores are free from arsenic and antimony, but are reported to carry, at times, very appreciable traces of both gold and silver, particularly the latter. The following assays of the gray ore from the Yancy mine in Person county, North Carolina, are given by Hanna,² and serve to illustrate the values of the mineral material.

Gold, per ton,	1-10 ounce,	1-10 ounce,	1-10 ounce.
Silver, per ton,	6 7-10 ounces,	5 1-10 ounces,	1-2 ounce.
Copper, per cent,	48.17	26.16	31.14.

In the Holloway shaft, 3.5 miles south of Virgilina, the vein has been opened to a depth of more than 500 feet, and the action of the percolating carbonated waters is shown to this depth in the occasional presence of the green carbonate, malachite, in association with the unaltered ores.

The particular interest in the ore deposits of this district is the somewhat analogous occurrence and association in many respects of the copper minerals, including native or metallic copper, in the greenstones (originally igneous in origin) to certain closely allied areas of altered igneous rocks of the Lake Superior region, and the Catoctin and South mountain areas of Virginia-Maryland-Pennsylvania, and to other smaller and less important areas in Virginia and North Carolina. Furthermore, the association of the copper with epidote is not only true of the Virgilina belt, but is described by various geologists³ as true

¹ The Minerals and Mineral Localities of North Carolina, Raleigh, 1885, 128 pages; also Bulletin No. 74, U. S. Geol. Survey, 1891, pp. 98, 109.

² Op. cit., p. 220.

³ Op. cit.

to some degree for the other areas of the Atlantic Coast and Lake Superior regions. No indications of amygdaloidal structure so common in the rocks with which the copper is intimately associated in many of the other areas is found in the Virgilina district.

In describing the general distribution of the Catoctin type of copper deposits, Weed says:

"It is evident that the association of epidote (and, to a lesser degree, of chlorite) and the native copper is a constant one, for which reason it is believed that the processes incident to the formation of the one led to the formation of the other. Such ores occur near Virgilina, Virginia, near Charlotte, North Carolina, and in many scattered localities through the South."¹

The Ducktown copper deposits in southeastern Tennessee have been shown by Weed² to represent a different type from the Virgilina deposits. Both Kemp³ and Weed⁴ agree that the Ducktown ores are replacement deposits of an original calcareous sedimentary. A further difference consists in the Tennessee deposits being composed chiefly of chalcopyrite and pyrrhotite, which minerals are essentially absent from the Virgilina district.

WEATHERING.

The superficial weathered product consists of a scanty covering of light gray to brown soil. At comparatively shallow depths beneath the surface the rock manifests no tendency toward disaggregation, nor to crumble and change color when exposed at the surface, but on the contrary remains hard and fresh appearing.

The greatly altered nature of these rocks has already been emphasized. The resulting minerals from such change, epidote and chlorite, are present in large amounts in these rocks, replacing in whole or in part the original essential minerals from

¹ Trans. Amer. Inst. Min. Engrs., 1891, vol. xxx, p. 503.

² Ibid., pp. 449-504.

³ Ibid., Richmond Meeting, February, 1891, pp. 18-20 (author's edition).

⁴ Ibid., 1891, vol. xxx, pp. 480-494.

which the above two have been derived. Epidote is usually regarded as a dynamo-metamorphic mineral, while chlorite is usually given as a product of weathering. The origin of chlorite, however, is sometimes closely associated with dynamic agencies. It is not possible, therefore, to separate the products of the processes which have produced the degree of alteration manifested in the rocks of this area. Without stating more detail, vastly the majority of change in the rocks of this area is due to dynamic action.

A suite of specimens representing the fresh and decayed rock were collected at the Anaconda mine in Virginia, a short distance north of Virgilina, for illustrating the chemical changes incidental to weathering. Here the decayed product is several feet deep, the brown color of the decayed rock passing gradually into the moderately fresh and firm green rock underneath. In columns VI and VII of the table of analyses are given chemical analyses of the fresh rock and its corresponding decayed product. The decayed rock was of a pronounced yellowish brown color, readily crumbling under slight pressure of the hand. It effervesced very feebly in dilute acid, indicating hardly more than appreciable traces of carbonates. When further digested for some time in very dilute warm HCl, the brown coloring matter was removed and the residue consisted of the usual green mineral products composing the fresh rock. The percentage of residue composed of the green colored minerals was very large.

As indicated in the analyses of the fresh and decayed rock of the table, the change has been one of hydration—the assumption of water, accompanied by the preoxidation of the iron and the partial removal of the more soluble constituents, lime, magnesia, and alkalis.

AGE RELATIONS.

Excepting the northernmost extension of the Jura-Trias to the south and southeast in the vicinity of Oxford, Granville county, North Carolina, no known clastics of definite age are found close to the area. Dikes of Mesozoic diabase are re-

ported to be rather numerous in parts of Granville county, and in several instances are observed cutting the rocks of this area. To the east, south, and west massive granites and granitic gneisses of approximately the same mineral composition are of frequent occurrence. Sufficient work has not yet been done, however, to definitely determine the exact origin of the gneisses, but in many cases their close mineralogical resemblance to the granites is suggestive of igneous origin. Indeed, a chemical analysis quoted by Kerr¹ of a similar granitic gneiss taken from the Raleigh quarries would strongly indicate, in connection with the mineral components, an original massive granite subsequently rendered schistose by pressure.

The occurrence of similar ancient volcanic rocks in the adjoining counties to the southeast of the Virgilina area, described by Williams² and others³ as closely resembling those of the South Mountain area, are grouped as pre-Cambrian in age, and can be most likely correlated with the rocks of the Virgilina district.

The rocks of this district are shown to be quite similar in many respects to the volcanics farther north in Virginia and Maryland of the Catoclin belt and of South Mountain, a continuation of the Catoclin belt in Pennsylvania. Keith⁴ has shown the rocks of the Catoclin belt to be pre-Cambrian—Algonkian—in age. Likewise Williams⁵ and Bascom⁶ have shown the series of both acid and basic volcanics of South Mountain in Pennsylvania to be of the same age—Algonkian.

¹ Geology of North Carolina, Geol. Survey of N. C., 1875, vol. i, p. 122.

² Jour. of Geology, 1894, vol. ii, pp. 1-31.

³ Gold Deposits of North Carolina, Geol. Survey of N. C., Bulletin no. 3, 1896, pp. 37-43; *ibid.*, Bulletin No. 10, 1897, pp. 15, 16.

⁴ Geology of the Catoclin Belt, 14th Ann. Rept., U. S. Geol. Survey, 1894, p. 319. See map, plate xxii, opposite p. 308.

⁵ Volcanic Rocks of South Mountain in Pennsylvania and Maryland, Am. Jour. Sci., 1892, vol. xlv, pp. 493, 494; Jour. of Geology, 1894, vol. ii, pp. 1-31.

⁶ The Ancient Volcanic Rocks of South Mountain, Pennsylvania, Bulletin No. 136, U. S. Geol. Survey, 1896, p. 30.

⁶ Jour. of Geology, 1893, vol. i, pp. 813-832.

The rocks of the Virgilina district are, with few exceptions, shown to be highly schistose in structure, which is a secondary structure, and indicates that the area has been subject to long-continued dynamo-metamorphism. In view of these facts and in the absence of contradictory field evidence, the rocks are placed as pre-Cambrian in age. This is in accord with the work of Kerr and Holmes, who agree in assigning the rocks of this area to the Huronian (Algonkian),¹ and with that of Keith,² Williams,³ and Bascom⁴ for somewhat similar volcanics occurring to the north in Virginia, Maryland, and Pennsylvania.

It further harmonizes with the work of Williams⁵ and Nitze⁶ in the adjoining counties to the southwest of the Virginia district, where similar rocks are described and classified as pre-Cambrian in age. Subsequent work will probably establish the contemporaneous origin of the rocks for the several scattered areas.

CONCLUSIONS.

The principal points developed in this study may be summarized as follows:

1. The rocks of the area here described have been greatly altered through pressure and chemical metamorphism, as indicated in the prevailing secondary schistose structure and the abundant development of the secondary minerals—chlorite, epidote, and hornblende—and small amounts of others. The alteration has advanced sufficiently far in the schistose phases to destroy in most cases the original structure and minerals of the rock.

2. From structural, petrographic, and chemical evidences the rocks are shown to have been derived from an original andesite, but in their present much altered state they are, according to present usage, more properly designated meta-andesites; that these are intimately associated with the corresponding volcanic clastics. Furthermore, the popular name greenstone

¹ Van Hise, C. R.: Correlation Papers, Bulletin No. 86, U. S. Geol. Survey.

² Op. cit.

³ Op. cit.

⁴ Op. cit.

⁵ Op. cit.

⁶ Op. cit.

applied to many areas of greatly altered massive and schistose rocks along the Atlantic Coast and Lake Superior regions, shown to have been derived from an original basic eruptive rock type, has equal application to the existing rocks of the Virgilina district.

3. The rocks are pre-Cambrian in age and represent an area of ancient volcanics similar to others described as occurring along the Atlantic Coast region from eastern Canada to Georgia and Alabama and in the Lake Superior region.

4. The rocks are cut by numerous approximately parallel quartz veins which contain workable copper deposits. The veins have been described as true fissure veins, and the ore is glance and bornite, without chalcopyrite and pyrite.

